Operational Stream Rehabilitation Trial at Clint Creek, Sewell Inlet

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FISH/FORESTRY INTERACTION PROGRAM

This study was undertaken as part of the Fish/Forestry Interaction Program (FFIP), a multi-disciplinary research study initiated in 1981. The program was started following a series of major winter storms in 1978 that triggered landslides over much of the Queen Charlotte Islands forest land base. Originating on steep slopes, many slides deposited tonnes of debris in streams and on valley flats. The events raised private and public concerns over logging practices on the Islands and prompted the establishment of the 5-year program. Overall objectives of FFIP were:

- to study the extent and severity of mass wasting and to assess its impacts on fish habitat and forest sites.
- to investigate the feasibility of rehabilitating stream and forest sites damaged by landslides.
- to assess alternative silvicultural treatments for maintaining the improving slope stability.
- to investigate the feasibility and success of using alternative logging methods, including skylines and helicopters, and by logging planning to reduce logging-related failures.

The program is jointly funded by direct appropriations from the Canada Department of Fisheries and Oceans, the B.C. Ministry of Forests (Research Branch), and the B.C. Ministry of Environment (Fisheries Branch). Participating agencies include Forestry Canada (Pacific Forestry Centre), and the Forest Engineering Research Institute of Canada (FERIC), Vancouver, B.C.

Program results are published through the B.C. Ministry of Forests, Land Management Report series, as well as in papers presented at symposiums, conferences, and through technical journals.

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SUMMARY

Large organic debris was introduced into Clint Creek, a small debris-torrented stream entering Sewell Inlet in the Queen Charlotte Islands in 1988. The study was conducted as an operational stream rehabilitation trial under the Fish/Forestry Interaction Program with the cooperation of Western Forest Products Limited. Three stone lines, 13 logs, and 6 root wads were installed within a 225 m reach in lower Clint Creek. The study design included a pre-rehabilitation survey to determine baseline fish and habitat conditions, an immediate post-rehabilitation survey to monitor initial changes, and a 7-month post-rehabilitation survey to determine structure durability and changes in habitat after a series of winter storm flows. No significant changes in stream width were evident after rehabilitation of Clint Creek. Number of pools in the thalweg increased from 4 before rehabilitation to 18 pools after, and to 13 pools 7 months later. Several sediment lobes dispersed with rehabilitation, burying two of the log emplacements and resulting in a more constant streambed slope gradient of 2.9% versus 2.0-4.7% gradient before rehabilitation. Greater channel definition during rehabilitation resulted in a 23% reduction in wetted area, but pool area more than doubled with rehabilitation. Reduction of the majority of overhanging vegetative cover with rehabilitation overwhelmed increases in other forms of rearing habitat cover. However, the critical overwinter rearing habitat tripled and habitat diversity more than doubled in Clint Creek after rehabilitation. Of the 13 log emplacements in Clint Creek, 8 (62%) remained unmoved after a series of large floods over winter. However, 50% of the logs were underscoured, reducing average pool depths but also adding diversity to the habitat available. Sediment storage areas averaging approximately 14 m^2 per log developed over the winter, indicating the log emplacements acted to stabilize the system. Conversely, streambank erosion resulting from rehabilitation averaged 1 m per log. Construction costs for rehabilitating Clint Creek totalled $6218 and averaged $366 per structure. Restoration guidelines were included in the report to facilitate industry cooperation in future operational stream rehabilitation projects.

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1 INTRODUCTION

Stream degradation resulting from old logging practices and mass wasting (Moring 1975; Meehan 1980; Tripp and Poulin 1986a, 1986b; Hogan 1986; Roberts 1987; Chamberlin 1988) was the impetus to this investigation of the suitability of stream rehabilitation in the Queen Charlotte Islands under the Fish/Forestry Interaction Program (FFIP), Phase I. An initial survey of stream rehabilitation methods (Bustard 1984) identified several promising techniques for use in the Queen Charlotte Islands, of which three were tested. Gabion weirs initially created excellent spawning and rearing conditions in low gradient stream reaches (Klassen 1984; Klassen and Northcote 1986, 1988). However, high installation cost and low durability indicated that gabions were not cost effective. The relatively low cost and initial success of a pilot log placement study (Tripp 1986) suggested that a more intensive investigation of log placement was warranted. Off-channel ponds were also tested with a pilot study that used explosives to create a pool in a small tributary. A follow-up study, funded through an unsolicited proposal (V.A. Poulin & Assoc. Ltd. In press), found that careful log placement successfully created salmonid habitat and sediment storage areas in debris-torrented streams, and that explosives were a suitable tool for creating valuable off-channel rearing habitat. The question remained whether log placement costs could be reduced during an operational trial.

The proposed operational stream rehabilitation trial incorporated techniques developed in the previous FFIP stream rehabilitation studies, and advanced them in work carried out cooperatively with Western Forest Products Ltd., Sewell Inlet operation. Improving rehabilitation site construction efficiency, while effectively rehabilitating Clint Creek and undertaking a cooperative operational study with industry, were the goals of this study.

The objectives of the operational stream rehabilitation trial were:

1. to undertake an operational field demonstration of rehabilitating a small stream using large organic debris (LOD) emplacements;
2. to evaluate the initial performance of operational habitat restoration using LOD emplacements;
3. to provide guidelines to facilitate industry cooperation in future operational stream rehabilitation projects and, where appropriate, recommendations for reducing costs and improving efficiency of operational procedures; and
4. to compare the fish habitat and durability of log emplacements in Clint Creek to those of previous FFIP stream rehabilitation projects.

2 STUDY AREA

The Sewell Inlet operation of Western Forest Products Ltd. consented to work with FFIP in undertaking an operational stream rehabilitation trial. Western Forest Products offered use of heavy equipment, materials, technical assistance, and logistical support toward rehabilitating a stream in their Moresby Island TFL 24.

Of several candidate streams accessible to the Sewell Inlet operation, Clint Creek (Figure 1) was selected as the study stream for several reasons:

- It had excellent access, flowing through Sewell Inlet camp.
- The stream was severely damaged by a debris torrent and was deficient in suitable salmonid rearing and spawning habitat.
- Sewell Inlet camp operated a fish hatchery using Clint Creek for a water supply. Adult chum salmon from the first release were expected to return in fall 1988, and there was poor spawning habitat.
- Clint Creek was a suitable size for rehabilitation (approx. 11 m wide) and was at a suitable stream gradient (averaging 2.6% in the lower 250 m).
- Abundant supplies of cull logs and root wads were available at a dryland sort located nearby.

Several factors were responsible for the lack of habitat in Clint Creek before rehabilitation. The debris torrent in the 1970's left a large levee alongside the lower portion of the stream and an alder flat upstream of the first bridge. It also removed or buried almost all natural instream large organic debris (LOD) and boulders. Without the presence of LOD or large boulders, floods did not generate scour pools or remove finer streambed sediments, and this resulted in a lack of suitable spawning and rearing habitat.

Clint Creek transported gravel quickly through the system because of its flashy nature. Water levels rise by almost a meter within a few hours during a rainstorm. Although the watershed size is relatively small (4.0 km^2), its location within mountains near the west coast leaves it vulnerable to violent rain squalls. For example, 120 mm of rain fell within a 24-hr period on 23-24 July 1988, causing an increase in discharge from 0.043 $m^3\ sec^{-1}$ to 8.9 $m^3\ sec^{-1}$ within 1 day – an increase in discharge of two orders of magnitude.

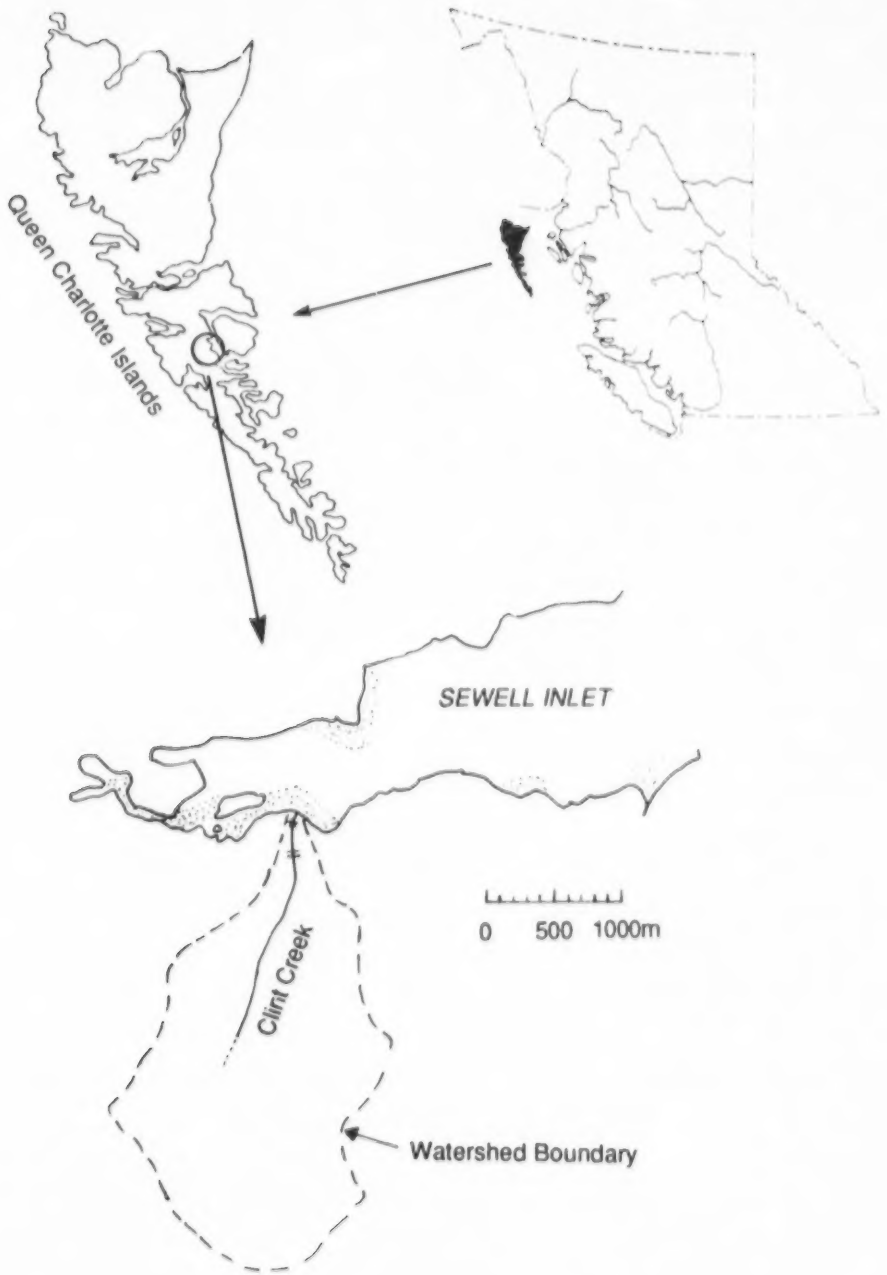

FIGURE 1. Clint Creek and watershed boundary at Sewell Inlet, Queen Charlotte Islands.

3 STUDY APPROACH

3.1 Study Design

The operational field trial for rehabilitating Clint Creek followed a working plan prepared for the FFIP Technical Advisory Committee. The study design included:

- a pre-construction site survey to establish baseline habitat values and fish populations;
- site construction;
- an immediate post-construction survey to document log positions and changes in habitat characteristics;
- and a 7-month post-construction survey to document log positions, changes in habitat, and fish distribution.

The pre-construction survey included a photographic inventory of the stream before log placement, a longitudinal profile of the thalweg, cross-stream widths, a fish habitat survey, and a fish population survey in the lower 400 m of Clint Creek. The baseline habitat and fish populations established here enabled a comparison of pre- and post-rehabilitative assessments.

Site construction in July 1988 involved selecting logs and root wads, skidding them to construction sites on the stream, burying in-stream anchors, carefully placing logs vertically and horizontally with a back-hoe, securing logs to the anchors, and clearing debris introduced into the stream. Construction activity was concentrated in the stream reach (2.6% gradient) below the second bridge. Thirteen logs were placed in the stream, with four of them coupled with root wads. Two additional root wads were anchored separately at the edge of the stream. Three stone lines were constructed in a 3.7% gradient reach upstream of the log emplacements to concentrate high flows toward the rehabilitated channel and away from developing side channels.

Stream clean-up consisted of removing debris introduced during construction, levelling gravel berms created by the heavy machinery, and seeding grass in disturbed streambank areas. Alder in riparian and overbank areas damaged by the heavy equipment during construction were felled and cleared from the stream channel.

As Clint Creek appeared to be gravel-deprived, Western Forest Products released gravel held behind a water supply dam on the stream to fill in sediment storage areas at the logs before the large run of chum salmon was expected to arrive in fall 1988. Releasing the gravel above the dam was regularly required to maintain the water supply for the Sewell Inlet camp.

A freshet occurred at Clint Creek 1 day after construction was completed. Two of the structures were re-anchored after the flood.

The immediate post-construction survey began as soon as the stream levels decreased. The longitudinal profile, stream cross section, and habitat surveys were repeated. The fish populations were also re-enumerated after the construction and the freshet. Log locations were documented in relation to

natural features. Emplacement sites were photographed for comparison to pre-construction and later follow-up records.

The 7-month post-construction surveys in February 1989 repeated the longitudinal profile, stream cross section, and habitat surveys. Baited Gee minnow traps were set overnight at pools at log and root wad sites to determine a winter fish distribution. All sites were photographed to illustrate habitat development at the sites.

3.2 Rehabilitation Structure Design

The rehabilitation sequence involved selecting log configurations, site spacing, and site locations. Candidate log configurations selected were variants of the successful diagonal cross-stream configurations developed in the 1986-87 stream rehabilitation study (V.A. Poulin & Associates Ltd. In press; D. Hogan, pers. comm.). In all cases, log butt ends were placed downstream and at a higher elevation than the upstream ends to provide high-flow backwater habitat. We attempted to bury the top of the upstream end flush with the streambed surface to provide fish passage at all flows. Root wads were placed at four of the sites to add further complexity to the scour pools, thus creating high quality over-winter rearing habitat. Root wads were cabled downstream at the end of the logs, in the vicinity of the anticipated scour pools. An additional two root wads were positioned separately where it was not feasible to place logs.

Anchors were installed at log emplacements to prevent the logs from floating as well as from being swept downstream during floods. As the overbank vegetation was not sufficiently large to anchor logs in Clint Creek, it was necessary to bury instream anchors. Truck tires filled with rock and buried 1.5-2.0 m below the streambed surface were used to anchor the logs. These were negatively buoyant and were installed more rapidly than the log deadmen used in the previous study (V.A. Poulin & Associates Ltd. In press).

The zone of influence around log emplacements established in the 1986-87 study (approx. 5 m) helped determine the optimal spacing between logs in Clint Creek. Distances selected between log emplacements (approx. 5-10 m) were anticipated to be sufficient to allow for a full-sized scour pool downstream and a gravel storage wedge upstream, with only a minimal riffle area between .

Log locations were selected by both: 1) a preliminary examination of a video presentation of Clint Creek (in consultation with FFIP program manager V. Poulin and fluvial geomorphologist D. Hogan); and 2) on-site field reconnaissance, which took into account log lengths available, local stream gradient, stream widths, local stream contours, and proximity to sensitive streambank areas. Logs were spaced as close as possible to maximize rehabilitative effects.

4 METHODS

4.1 Site Evaluation

4.1.1 Cross sections

Cross sections were measured at regular intervals (15 m) along Clint Creek. Distances from the thalweg to the wetted channel edge and to the rooted vegetation were measured to both right and left streambanks. Benchmarks located in overbank areas established references for follow-up cross-section surveys. Cross-section data were combined with stream feature measurements to form a baseline map. The thalweg was used as a center line on the baseline map, with stream and channel widths from the cross sections indicated relative to the thalweg. Relative log positions and orientations were symbolically indicated on the map.

4.1.2 Longitudinal profiles

Longitudinal profiles of the study reaches were surveyed with an automatic level (Kern), stadia rod, and hip chain before construction, immediately after construction, and 7 months after construction during winter low-flows. Elevations of the streambed and water depths were measured at breaks in stream features (riffles, pools) and at depth in pools, and related to stationary bench marks (D. Hogan, pers. comm.). Stream features were numbered sequentially upstream along the profile and this was used for other survey components (habitat and fish distributions). Log orientation to the bank, and position relative to the stream feature numbering system, were also documented. Streambed elevations and water depths relative to a permanent benchmark were plotted for the three profile surveys to enable comparisons before and after site construction.

4.1.3 Rearing habitat

Low-flow habitat was assessed for each stream feature in the study reaches. Feature width, length, water depth, overhanging vegetation area, LOD number and area, small organic debris (SOD) area, deep water, boulder backwater area, and turbulence area were measured as described in Tripp and Poulin (1986a) and in accordance with Bisson *et al.* (1982). The habitat data were summarized and tabulated on a computer spreadsheet. Low-flow habitat values were summed for feature types (pools, riffles) and origin (natural, emplacement). Habitat diversity indices were calculated for total stream reaches and for pool areas, to enable comparison to values found in other studies.

4.1.4 Fish populations

Fish populations were estimated using a mark-recapture technique. Fish caught in the first pass were marked by caudal fin clip, then measured and redistributed according to the number of fish originally captured in each pool and riffle. In the second pass, 6-24 hours later, marked and unmarked fish were recorded separately for each feature, and the total number of fish present was estimated through mark-

recapture calculations (Bailey 1951; Ricker 1975). Stop nets were not required, as the entire reach was sampled in each pass, and it was assumed that any movement was similar among marked and unmarked fish. Fish sampling involved passes with a Smith Root model VIII A electroshocker and the setting of baited Gee minnow traps in pools. Formulas for calculating population sizes and 95% confidence limits are outlined in Appendix 1.

4.1.5 Photography

Sites were photographed from the ground at marked "photo points" before and after site construction. Photographs showing habitat creation at log sites were selected to represent effective LOD structures.

4.2 Site Construction

Candidate log emplacement sites were flagged following site selection and before construction. Spacing between log sites was shorter in Clint Creek than in the earlier Macmillan and Southbay Dump creeks projects where log spacing attempted to mimic natural log spacing of two to three bankfull widths (Hogan 1986). In Clint Creek, logs were spaced closer, often within one bankfull width. Inter-log spacing (excluding the area around the first bridge) in Clint Creek averaged 11.5 m, or 114% the average rooted width of 10.1 m (Table 1).

Twenty logs and six root wads were selected from culls marked for burning at a dryland sorting area east of Clint Creek. Logs 0.7-1.0 m diameter at the butt and preferably long enough to span the wetted stream at a 45° angle were marked, loaded onto a logging truck, and hauled to the stream. Root wads were hauled to the stream with a Cat 980 loader.

At the stream, logs were carried to designated sites for installation by a tracked Hitachi excavator equipped with a stiff opposing "thumb" on the boom and a 1.5 m^3 bucket. The excavator travelled along the stream channel on gravel bars where possible, to maintain integrity of the steep streambanks that were recovering from a debris torrent in the 1970's. Holes 2 m deep were excavated to bury the truck tire anchors, which were positioned just upstream, and near each end, of the designated log sites. Excavated material was largely kept out of the channel and placed on the streambank or temporarily on gravel bars. Trenches were then excavated into the streambed and streambank to enable careful vertical placement of the logs. The butt ends of logs were buried up to 2 m into the streambank to prevent erosion around the end of the log. The tops of the downstream butt ends were 0.5-1 m above the streambed surface, whereas the tops of the upstream ends of the logs were buried at a lower elevation to concentrate water flow at the upper end of the log. Logs of insufficient length to span the stream at a 45° angle were placed at a lower angle. Root wads were placed on the downstream side of the butt ends of four logs. Two more root wads were positioned in the stream to create high-flow habitat, and one was placed at the top end of a side channel.

Thirty-eight lengths of new either 12- or 20-m seven-strand bundling wire (5/8" diam) with crimped 20 cm end loops (aluminum sleeves crimped four times) were used for securing the logs to the tire anchors. At the tire end, the cables were passed through the hole in the tire and then through a crimped end loop to form a loop through the tire. The other ends of the cables were attached to the logs by wrapping the cable 1.5-3.0 times around the log. Each wrap was tucked under the previous wrap, and all the wraps were fixed with two cable staples (Figure 2). The wraps were cinched tight by the excavator (either using chains or by placing the crimped end loop over a tooth on the bucket) while being secured by staples (~3 x 9 cm). Root wads were securely cabled to log butt ends by a similar cinching and stapling method.

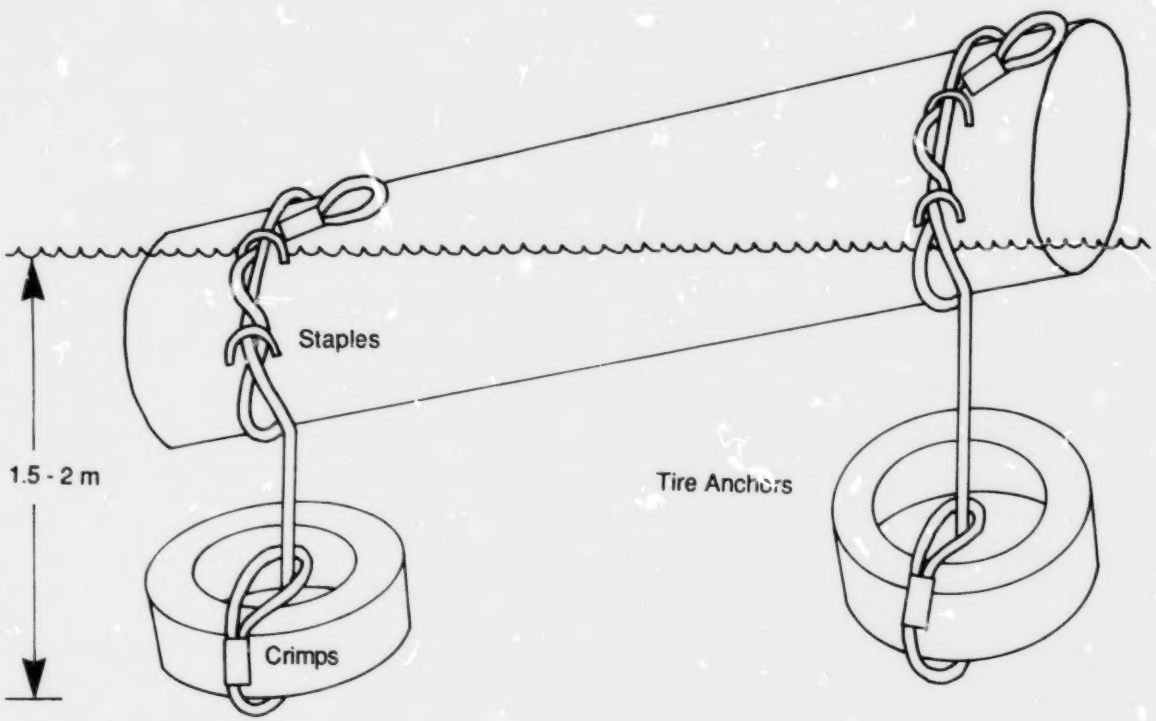

FIGURE 2. Schematic of technique for securing logs to anchors.

Site cleanup involved manual removal of branches, bark and other debris introduced to the stream from the construction process. Debris was removed to overbank areas. Gravel berms created by the machinery were levelled. Exposed streambank areas, such as where butt ends were inserted and the excavator made access, were hand-seeded with a fertilized grass-legume mix. Riparian vegetation damaged by the construction process was removed.

Equipment time and manpower requirements were recorded for each site. Overall project costs were tabulated and summarized.

4.3 Comparative Survey of Other FFIP Stream Rehabilitation Projects

As an extension to the primary operational stream rehabilitation trial in Clint Creek, results of previous studies undertaken by FFIP were examined and compared to those of Clint Creek. Log structures placed in Macmillan, Southbay Dump, and Sachs creeks in 1986 (V.A. Poulin & Assoc. Ltd. In press) and in Southbay Dump Creek in 1982 (Tripp 1986), and gabion weirs (wire cages partially buried into the streambed and filled with rock) constructed in Sachs Creek in 1982 (Klassen 1986) were all surveyed after a series of major floods in February 1989. Previous examination of these structures preceded any major flood events, leaving unanswered questions about their effectiveness and durability.

The survey consisted of measuring representative physical parameters that summarized streambed configurations and structure stability. Streambed configurations were represented by counting the number of pools per log or weir (upstream and downstream), measuring their length and width to calculate the pool area, and measuring the length and width and calculating the area of sediment storage areas. Sediment storage areas were defined as gravel bars associated with the structures that were above water level at time of surveying. Surveys were conducted during winter low flows. Structure stability was indicated by whether a log or weir had moved at all since placement. The length of eroded streambank upstream and downstream of the structures was also measured as an indication of streambank integrity.

All values were summarized in Appendix 2 and graphically reported on a per-log or per-weir basis in the text. In the case of the initial 1982 log placement study in Southbay Dump Creek, where 7 of the 14 original logs were missing from the channel, the values reported were per original log installed.

5 RESULTS AND DISCUSSION

5.1 Physical Changes to Clint Creek

5.1.1 Changes in stream widths

Stream width did not change significantly with rehabilitation in Clint Creek. From analysis of the 15-m interval cross-section measurements, the rooted stream width remained about the same in the rehabilitation area, whereas the wetted width tended to decrease, though not significantly (Table 1). In the unrehabilitated region upstream of the second bridge, both categories tended to decrease, though neither significantly. Factors affecting stream width include the log placements, varying flow rates, changes in bedload supply affecting streambed elevations, and growth or decay of moss and rooted vegetation. Bank-to-bank thalweg meandering was not indicated by the individual right or left bank values nor their standard deviations.

Plots of cross-section data indicated minor shifts in thalweg relative to wetted and rooted stream boundaries (Figure 3). However, it was difficult to identify any thalweg shifts to the right or left as a direct result of log placement and orientation as indicated by the schematic in Figure 3.

TABLE 1. Changes in stream width with rehabilitation of Clint Creek, 1988 and 1989

Category[a]	Before 13 July 1988				After 27 July 1988		7 months after 2 March 1989			
	Rehab.		Upstream		Rehab.		Rehab.		Upstream	
	Avg (m)	S.D. (m)	Avg (m)	S.D. (m)	Avg (m)	S.D. (m)	Avg (m)	S.D. (m)	Avg (m)	S.D. (m)
Rooted width from thalweg										
Right	5.7	2.8	6.2	2.5	5.9	3.5	5.6	2.8	4.5	2.3
Left	5.3	2.3	4.7	2.7	5.3	2.7	5.3	2.5	4.5	3.1
Total rooted width	10.9	2.7	10.9	3.3	11.2	3.2	10.9	2.9	9.0	4.9
Wetted width from thalweg										
Right	3.4	1.2	4.3	2.4	3.4	2.1	2.6	1.1	3.0	1.8
Left	3.0	1.8	3.8	2.7	3.0	1.7	3.4	1.9	4.1	2.7
Total wetted width	6.4	2.2	8.1	4.0	6.4	2.6	5.9	2.1	7.2	3.8

[a] Rehabilitation reach: N = 16 cross sections within the active rehabilitation area (Cross Section XS 30 to XS 255).

Upstream reach: N = 6 cross sections upstream from the active rehabilitation area (Cross Section XS 270 to XS 345).

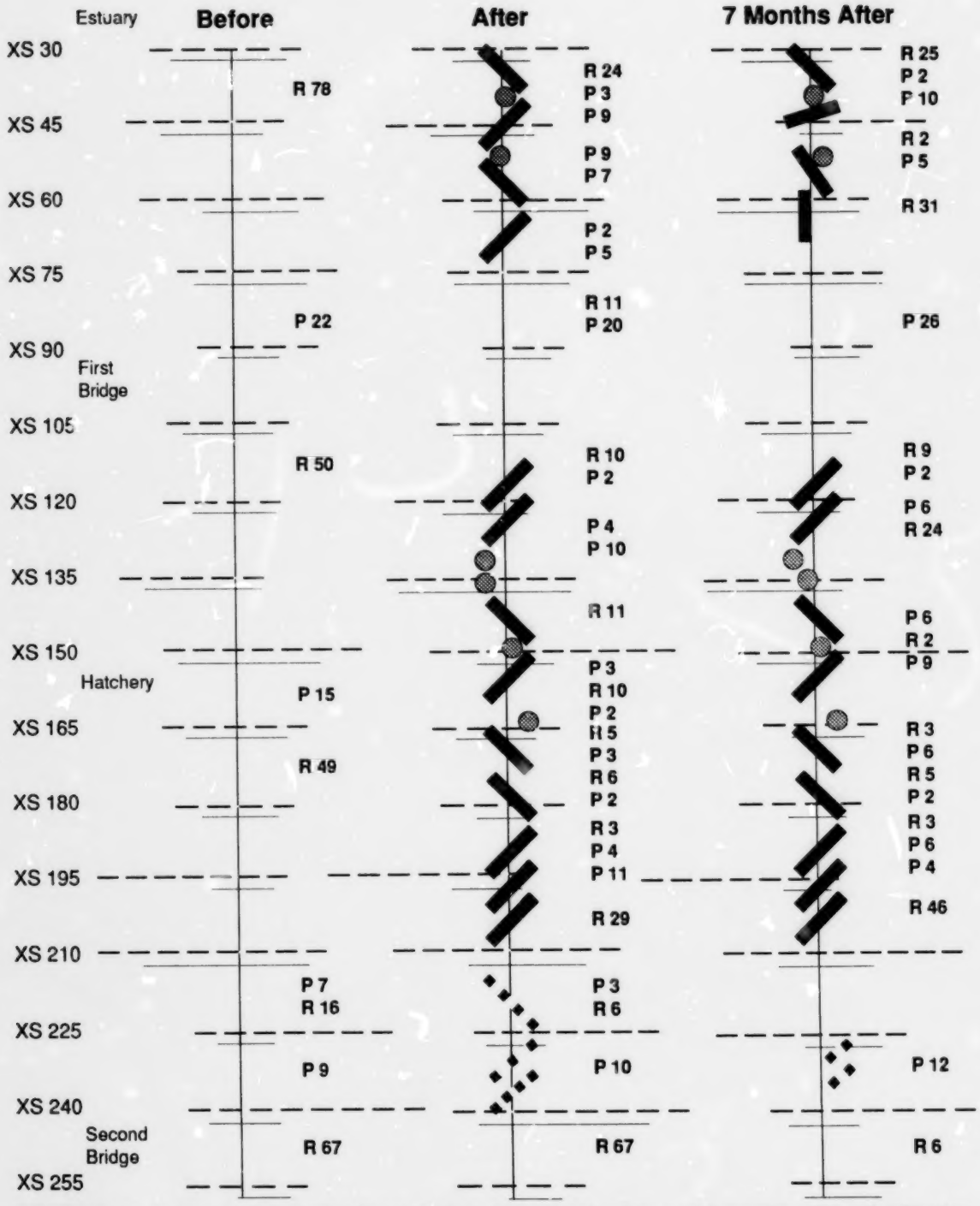

FIGURE 3. Stylized features of Clint Creek before, immediately after, and 7 months after rehabilitation, 1988 and 1989. Rooted (dashed horizontal lines) and wetted (horizontal lines) stream widths were measured from thalweg at 15-m interval cross-sections (XS). Log orientations (diagonal lines), root wads (shaded circles) and stone lines (dashed diagonal lines) are symbolized. Relative pool (P) and riffle (R) positions and lengths (in meters) are shown.

5.1.2 Changes in longitudinal profile

The LOD and stone line placement in Clint Creek diversified stream contours, creating many steps and pools that did not exist before rehabilitation (Figure 4). Before rehabilitation, only four pools were evident on the longitudinal profile, with the one under the first bridge predominant. Immediately after rehabilitation, 18 pools were indicated by the longitudinal profile. Seven months after rehabilitation, 13 pools were evident. The increased number of pools with rehabilitation was reflected in the habitat analysis discussed further in section 5.1.3.

Although no thalweg meandering was indicated in the cross-section data, the longitudinal profiles suggested that the thalweg meandered more after rehabilitation (Figure 4). Increased thalweg meandering from bank to bank helped reduce stream gradients during low flows, but the effect during high flows would have been less, with the main flow passing more directly down the middle of the rooted channel.

The longitudinal profiles indicated two or three sediment lobes before rehabilitation which were not apparent afterwards (Figure 4). The lobes were reflected in the slope gradients. The slope before rehabilitation was broken into distinct reaches of varying gradients ranging from 4.7 to 2.0% above the first bridge. However, after streambed manipulation through log placement and 7 months of floods, the stream gradient became a more constant 2.9% over the entire reach, with the lobes being much less prominent. The evidence of lobe migration appeared in the uppermost two log sites, which became buried by the time of the 7-month survey, discussed further in section 5.3.

The high intensity of the floods washed out the three stone lines in the upstream portion of the rehabilitation reach (Figure 4). The main purpose of the stone lines was to dissipate high-flow energies and maintain flow direction toward the rehabilitation reach and away from ephemeral side channels, rather than to influence habitat character.

5.1.3 Changes in fish habitat

Stream thalweg length remained nearly the same from before to after rehabilitation in Clint Creek, as measured during the habitat surveys. The slight increase in length after rehabilitation (Table 2) reflected the increase indicated by the longitudinal profile measurements (Figure 4). The increase in length may have been from increased thalweg meandering during low flows. However, thalweg straightening during high water probably had little influence on geomorphic processes.

The substantial 23% reduction in wetted area after rehabilitation (Table 2) reflected increased channel definition. Clint Creek tended to have a flat and wide channel area before rehabilitation, and this deepened and became narrower as flows were directed from one log to the next. Widths decreased despite slightly higher water flows (7 cm higher on a staff gauge) during the post-construction surveys.

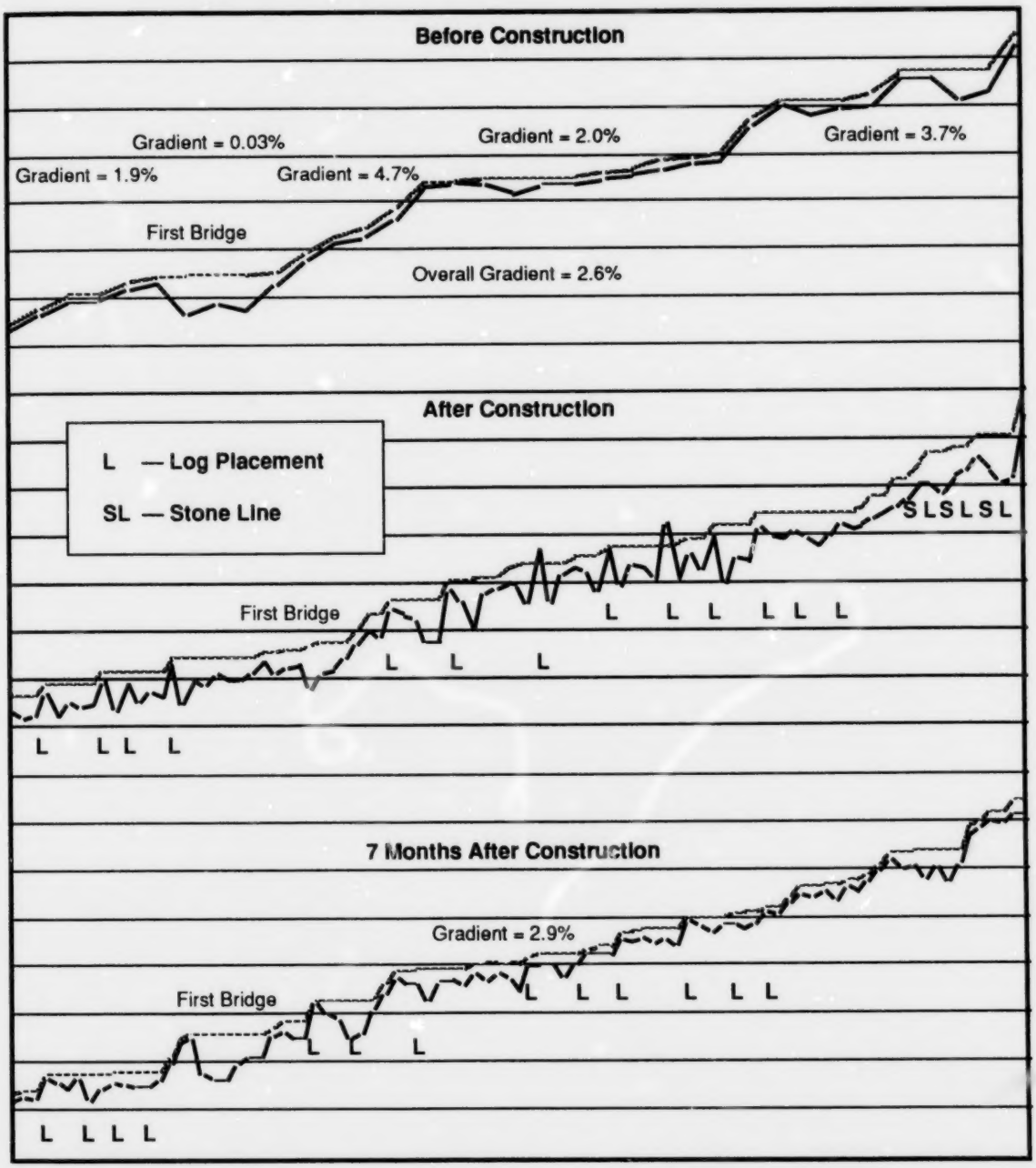

FIGURE 4. Longitudinal profiles of Clint Creek before construction (12 July 1988), immediately after construction (25 July 1988), and 7 months after construction (3 March 1989). Horizontal reference lines were in 1-m vertical intervals. Horizontal distance represented the same stream segment (from XS30 to XS255), but thalweg length varied: 229 m before construction, 243 m after construction, and 237 m 7 months after construction. Water surface elevations indicated by dashed lines were calculated from water depth at time of surveys.

TABLE 2. Instream, low-flow habitat conditions before construction (12 July 1988), immediately after construction (25 July 1988), and 7 months after construction (3 March 1989)

Variable	Before 13 July 1988		After 27 July 1988	7 months after 1 March 1989	
	Rehab.	Upstream	Rehab.	Rehab.	Upstream
Stream length (m)	310.9	124.7	314.4	323.9	121.0
Wetted area (m^2)	1912	743	1473	1488	572
Pool characteristics:					
Pool area (%)	15	12.8	44	38	18
Pool depth[a]	34	30.6	52	21	26
Pool no.	13	7	27	24	8
No. types[b]	4	3	6	5	3
Major type	BP, LSP	BP, PP	PP, DP	BP, PP	BP, PP
Surface substrate:					
% fines (<5 mm)	17	17	15	12	c
% gravel (5-63 mm)	27	17	30	25	22
% larges (>63 mm)	56	66	55	63	72
Cover characteristics[c]:					
LOD	3.1	0.3	9.3	8.1	1.0
SOD	0.3	0.0	0.3	0.4	0.1
Deep water	4.0	9.0	35.8	13.0	13.6
Rock	1.1	1.2	0.9	1.2	1.9
Undercut banks	0.0	0.2	0.0	0.1	0.2
Turbulence	1.5	2.4	9.2	0.8	2.0
Vegetation	34	1.9	7.2	1.5	5.1
Total[d]	43.7	15.0	62.7	25.1	23.9
Total winter[e]	5.7	0	33.1	18.5	0
Habitat diversity (H')[f]					
Total	0.76	0.75	1.88	1.80	0.96
Pool	0.56	0.56	1.40	1.37	0.72

a Average maximum pool depth minus average maximum riffle depth (cm).

b Six pool types as follows: LP = lateral scour pool, BP = backwater pool, PP = plunge pool, UP = underscour pool, DP = Dam pool, SP = side pool.

c Sum of percentages in each of above cover types.

d Expressed as percent of wetted area.

e Sum of percent LOD, undercut banks, rock and deepwater cover in LOD-controlled pools.

f Habitat diversity index $\Sigma H' = \frac{3.32193 (A \log A - a_i \log a_i)}{A}$

where: A = total wetted area, a_i = wetted area of the i^{th} habitat type (riffles, each pool type) and areas are expressed as a proportion of the whole area.

Pool habitat at Clint Creek showed substantial changes after rehabilitation. Pool area and number more than doubled (Table 2). This contrasted with an approximate 50% increase in pool area and number of an unrehabilitated reach upstream of the second bridge. Some of the increases in pool area may have been from the higher flows during the latter surveys. Maximum pool depths similarly increased with rehabilitation, but decreased substantially after winter floods, possibly from loss of plunge pools and formation of underscour and backpools. Increased flows from the pre- to post-rehabilitation surveys were accounted for in the depth calculations; depths were calculated as the pool depth less the riffle depth downstream. Number of types of pools also increased with rehabilitation. The major type of pool shifted from backwater pool and lateral scour pool before rehabilitation to dam pool and plunge pool after rehabilitation (Plate 1). These changes in pools were reflected in the longitudinal profiles (Figure 4).

Pool dimensions after rehabilitation in Clint Creek were initially larger than those in Macmillan and Southbay Dump creeks after rehabilitation, measured before major floods, with pool areas of 36% and 37%, respectively, and pool depths of 37 cm and 47 cm, respectively (V.A. Poulin & Assoc. Ltd. In press). After the floods, the number of pools and area of pools per log in Clint Creek exceeded those of all other log emplacement studies (Figures 5 and 6), possibly again from the larger diameter of logs used in Clint Creek creating more of a hydraulic response. Pools tended to form more downstream of the log

PLATE 1. Dam pool and plunge pool formation at log emplacement site 5, Clint Creek, February 1989.

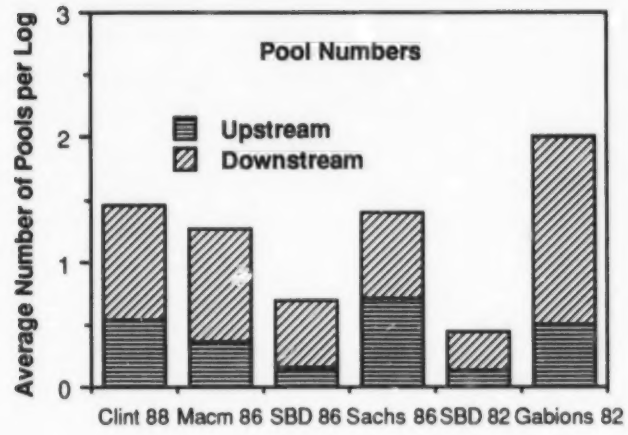

FIGURE 5. Pool abundance at rehabilitation sites in Clint, Macmillan (Macm), Southbay Dump (SBD) and Sachs creeks, February 1989. Year of rehabilitation indicated beside the stream names, with gabions constructed in Sachs Creek.

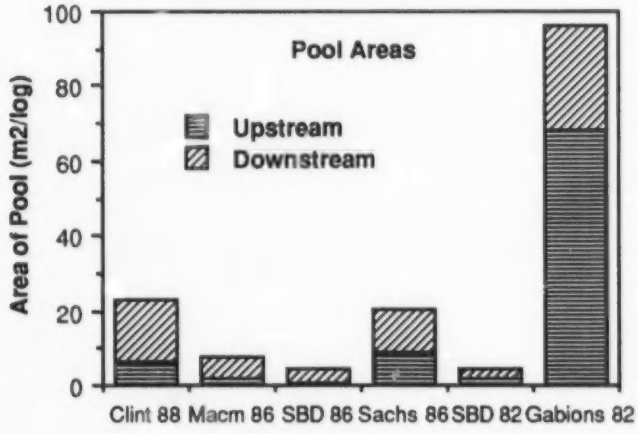

FIGURE 6. Pool area at rehabilitation sites in Clint, Macmillan (Macm), Southbay Dump (SBD) and Sachs creeks, February 1989. Year of rehabilitation indicated beside the stream names, with gabions constructed in Sachs Creek.

emplacements than upstream, whereas at the gabion sites the massive dam pools upstream dominated over the plunge pools downstream of the weirs. The effect of LOD placement on pools in Clint Creek was similar to results of placing enhancement structures in East Fork Lobster Creek, where increased number, size and quality of pools were found (House and Boehne 1985).

Surface substrate at the LOD sites in Clint Creek did not change substantially with rehabilitation (Table 2). Clint Creek showed surficial gravel characteristics within a couple of percentages of those found at torrented Macmillan Creek after rehabilitation (V.A. Poulin & Associates Ltd. In press). However, a higher gravel fraction and fewer larges were found after rehabilitation in torrented Southbay Dump Creek. Unlike Clint and Macmillan creeks, Southbay Dump Creek was subjected to repeated torrenting in recent years. In addition, before and immediately after rehabilitation of Clint Creek, substantial quantities of gravel were caught and stored above a water supply dam, resulting in gravel deprivation throughout the study reach downstream. The gravel subsequently excavated behind the dam and released downstream before the floods did not appear to have settled in the study reach nor in the reach upstream of the second bridge, as indicated by the coarse 7-month post-rehabilitation substrate values (Table 2). This released gravel possibly moved through the entire system during the flood, leaving little gravel to settle at the sites during the receding limb of the hydrograph .

Rearing cover characteristics underwent substantial changes with rehabilitation at Clint Creek. The LOD cover almost tripled in the rehabilitation reach (Table 2). Deep water habitat initially increased nearly 10 times with rehabilitation, but later declined with the floods to more than triple the pre-rehabilitation values. This correponds to a 50% increase in deep water habitat in the unrehabilitated reach upstream of the second bridge. Turbulence habitat, as indicated by frothy water, initially increased over 500% with rehabilitation, but later decreased after the floods to less than one-half of the pre-rehabilitation values. The amount of vegetative cover decreased substantially with rehabilitation, both as a function of damage and removal with the heavy equipment and of the decreasing stream widths. This major loss of summer habitat (79% of initial riparian vegetation cover) was greater than that recorded at Southbay Dump Creek (53%), Macmillan Creek (8%), and Sachs Creek (17%) in an earlier rehabilitation study (V.A. Poulin & Assoc. Ltd. In press). The higher frequency of log placements and the greater initial vegetation cover in Clint Creek was partially the cause of the decrease. Part of the loss in vegetative cover was a function of the reduced wetted area and stream definition of the channel away from the streambanks. Much of the streambank had overhanging vegetation over shallow backwater areas which became dry as the thalweg deepened after rehabilitation. In total, summer rearing habitat initially increased by almost 50% with rehabilitation, but decreased substantially below pre-rehabilitation values after the floods. The decrease from the pre-rehabilitation values was more than accounted for by the reduction in vegetative cover.

Overwinter rearing habitat increased substantially with rehabilitation at Clint Creek. Overwinter habitat, as defined by LOD area, undercut banks, boulder areas, and deep water area in LOD-controlled pools, initially increased nearly 6 times to 33.1% of the wetted area, before settling to 18.5% or triple the pre-rehabilitation values (Table 2). Post-flood overwinter rearing habitat values in Clint Creek were comparable to the pre-flood values in Macmillan Creek (13%) and Southbay Dump Creek (20%) (V.A. Poulin & Assoc.

Ltd. In press). Overwinter habitat in Sachs Creek (52%) was substantially greater than that in Clint Creek, and was probably related to the large pools that developed in the lower gradient sites.

Habitat diversity both in pools and over the whole study reach more than doubled in Clint Creek with rehabilitation (Table 2). Habitat diversity both before and after rehabilitation were within the range of those found in rehabilitated Macmillan, Southbay Dump and Sachs creeks before the floods (Figure 7). Post-flood habitat diversity values were not available for the latter streams, but appear to have decreased in the comparable Macmillan and Southbay Dump creeks with sediments filling in some of the pools.

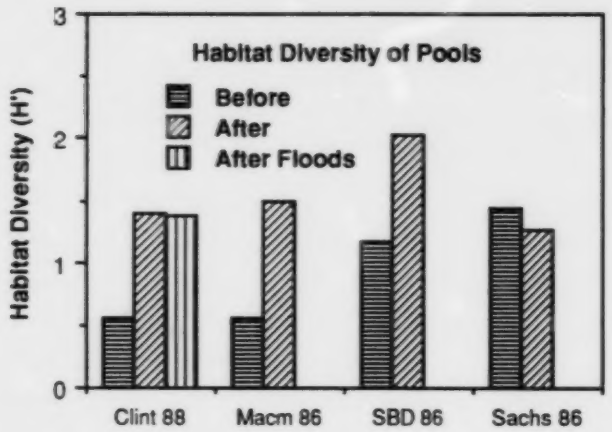

FIGURE 7. Pre- and post-rehabilitation pool habitat diversity in Clint, Macmillan (Macm), Southbay Dump (SBD) and Sachs creeks. Data for Macmillan, Southbay Dump and Sachs creeks taken from V.A. Poulin & Associates Ltd. (In press) where no post-flood data were available.

5.2 Fish Utilization

Populations of juvenile coho salmon (*Oncorhynchus kisutch*), resident Dolly Varden char (*Salvelinus malma*), and sculpins (family Cottidae) resided in Clint Creek. The numbers of Dolly Varden and sculpins were too low to generate population estimates. No 1+ coho were captured in the surveys, suggesting that there was no natural spawning in the system and that the 0+ coho fry likely had escaped from a hatchery located on its bank. The presence of these escaped fry meant their densities could be followed through the rehabilitation and a flood (~8.9 m^3 sec^{-1}) that occurred the day after construction was completed. The coho population in Clint Creek declined in this period from 3.8 to 1.5 fish per meter stream. Although natural declines in juvenile populations occur rapidly over this time period, substantial portions of the observed decline were probably from both the flood and the instream work.

5.3 Structure Durability

Physical factors considered in assessing durability of rehabilitation structures represented the structure's ability to withstand the forces of the stream during flood. This was measured from movement of the structure, changes in flow patterns around or under the structure, streambank erosion at the sites, burial of the structure by sediments, and effective stabilization of mobile stream sediments.

Log emplacements

The durability of the log emplacements varied considerably between studies conducted by FFIP in the past 7 years. In Clint Creek, 62% of the logs did not move during the floods, whereas 70-85% of logs had not moved since placement in Macmillan, Sachs and Southbay Dump creeks in the 1986 study and all of the logs moved in Southbay Dump Creek in the 1982 study (Figure 8). The high instability of the 1982 logs reflected the lack of geomorphological design and anchoring. After extensive geomorphic and hydrological engineering design for the 1986 study, the relatively few logs that moved there were often components of multiple-log arches and shifted usually less than 1 m. Over-bank anchoring cables for the majority of the logs, however, remained slack, suggesting that appropriate levels of backfilling and riprapping for the size and depth of log placements were achieved during construction. The Clint Creek log emplacements that shifted relied heavily on their anchors to retain their new positions. It appeared that none of the tire anchors shifted with the stress exerted by the logs during the floods. Some of the anchors were initially positioned too far upstream to hold the logs down effectively when backfill was eroded off the logs.

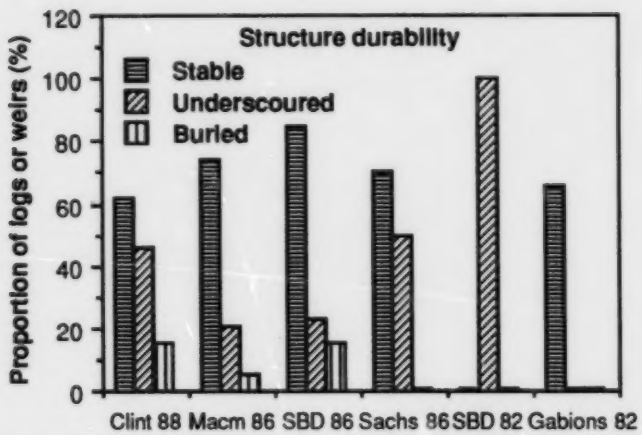

FIGURE 8. Durability of stream rehabilitation structures in Clint, Macmillan (Macm), Southbay Dump (SBD) and Sachs creeks, February 1989. Year of rehabilitation indicated beside the stream names, with gabions being those constructed in Sachs Creek.

Some of the shifting of log emplacements was from erosion of backfill sediments from under the downstream side of the logs, and resulted in flow under – rather than over – the log emplacements. Underscour occurred at all of the 1982 study emplacements, at between 21 and 50% of the logs in the 1986 study and at 50% of the logs in Clint Creek (Figure 8). In the 1982 study, underscour developed simply as the logs floated during the floods. Underscour in the 1986 study was often associated with multiple-log arches where the top logs or logs with ends raking steeply onto the streambank were placed too high in the channel to stabilize the backfill they were pre-filled with. For example, the highest degree of underscouring was observed in Sachs Creek where all logs placed were components of log arches (Plate 2). Minimal underscouring was observed with single, small-diameter logs placed at shallow vertical angles oblique to the streambed, with the lower end buried well into the streambed.

The high degree of underscour of log emplacements (50%) in Clint Creek (Figure 8) probably resulted from several factors other than high vertical placement. The key factor was probably the large size and species of log used, which provided substantial hydraulic and buoyancy forces during floods. Rather than western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*) as were used in the other rehabilitation projects, yellow cedar (*Chamaecyparis nootkatensis*) was available near Clint Creek and was attractive for its high resistance to decay. Subsequently, yellow cedar was selected for 11 of the 13 log

PLATE 2. Underscour pool formation at multiple-log arch emplacement site 4, Sachs Creek, February 1989.

emplacements in Clint Creek. The high resin content of yellow cedar not only deterred decay, it also resisted water penetration, leaving logs relatively buoyant for long periods. Western hemlock, however, tended to become waterlogged and negatively buoyant within several months. The buoyant forces have been calculated for the Clint Creek log emplacements (Appendix 3) and range up to 3270 kg. All five logs that floated during the floods were yellow cedar. The large Sitka spruce used at site 6 also had a high maximum buoyancy value (2940 kg) but did not float, possibly from being partially waterlogged. However, this large spruce was underscoured, probably from placement too high in the channel for its large size, and sediments were eroded out from under the log from the downstream side.

Although many logs were underscoured, underscouring was not considered to be a problem. The pools that formed from the underscouring of logs added to the diversity of habitat available. Underscour pools appeared effective as juvenile rearing habitat and particularly effective as adult-holding areas (Plate 3). Future rehabilitation designs may best manage for all components of the salmon life cycle and include some underscour pools in their plans.

PLATE 3. Underscour pool formation at log emplacement site 9, Clint Creek, February 1989.

Where underscour is not desired, scouring under log emplacements can be prevented with uthe use of a technique developed in the Pacific Northwest (King 1988). A fence or skirt attached to the log and buried into the streambed upstream catches sediments in front of the log and prevents turbulence in the

plunge pool downstream from eroding sediments under the log. Fencing material could be gabion mesh or Geogrid, a synthetic soil reinforcement material manufactured out of a stretched sheet of polymer plastic to form a durable, lightweight high tensile strength grid. If used in sufficient quantities, such a mesh would preclude the need for anchors and save construction time. The mesh could also help in sinking the logs in their trenches. A common problem with vertical positioning was to sink the logs to the bottom of their (flooded) trenches before backfilling and locking them in position. If the logs were not sunk to the bottom of their trenches, it was difficult to get the logs to the desired depth and angle into the streambed. Using a mesh and backfilling the mesh side of the log first gives better control to the vertical positioning of the logs.

Some of the emplacements became ineffective by being buried under streambed sediments. Burial was not caused by logs being positioned too deep in the channel, but by sediment lobe migration occurring over the site (section 5.1.2). Burial by sediments was observed at 0 - 15% of log emplacements in all FFIP studies (Figure 8). With the high availability and mobility of sediments in these flashy Queen Charlotte Islands streams, it may be expected that a certain portion of structures in a system would be buried at any given time, and to reappear at some later date. Fan development over the long term, however, would dictate that eventually more structures would be buried than would reappear. A geomorphological perspective of candidate streams with regard to stage of channel downcutting, channel stability and upstream processes would therefore be important before designing rehabilitation structures for a system.

Large organic debris often acts to stabilize streambed sediments by collecting relatively mobile material in lower velocity areas associated with logs (Hogan 1986). Sediment storage areas were well developed at log emplacements. In the 1982 study, two log jams that formed from log emplacements collected the greatest area of sediment (Figure 9). In the 1986 study, sediment storage areas of 18.1 m^2 and 30.1 m^2 were associated per log, while Clint Creek emplacements had slightly less at 14.4 m^2 per log. Sediment storage areas tended to be more abundant upstream of the logs than downstream, except in lower gradient Sachs Creek which had substantially more sediment storage downstream of the logs. The tendency for greater sediment storage area development upstream and greater pool development downstream of log emplacements (Figures 5 and 6) suggests different velocity patterns existed during floods, upstream to downstream of the logs. This diversity of flood velocities around the logs was responsible for sediment sorting, an important factor in creating spawning habitat.

Streambank erosion at log emplacements was observed in all FFIP study streams, with averages ranging from 3.6 m per log in the 1982 study, to between 1.9 and 7.7 m per log in the 1986 study and 1.0 m per log in Clint Creek (Figure 10). Streambank erosion occurred more frequently downstream of the log emplacements than upstream, where velocities were greater and flows had been directed laterally as they crossed the logs. Erosion was often characterized by undercut banks, generating additional rearing habitat. Occasionally, young alder trees toppled into the stream channel from the undercut banks and added rearing cover to the site. Sediment entrainment from bank erosion probably occurred during peak flows, and joined an already sediment-laden discharge with supposedly little additional effect on fish.

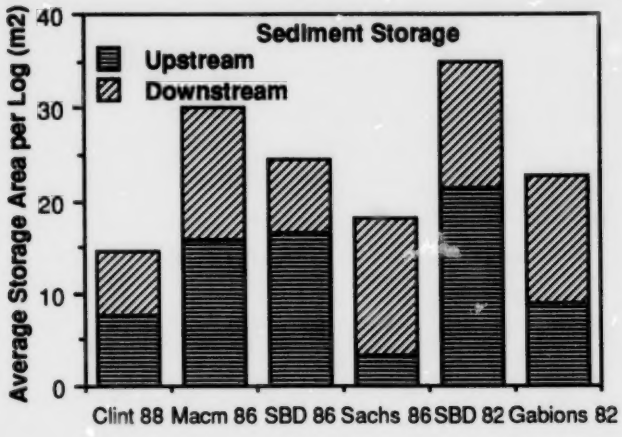

FIGURE 9. Sediment storage areas at stream rehabilitation structures in Clint, Macmillan (Macm), Southbay Dump (SBD) and Sachs creeks, February 1989. Year of rehabilitation indicated beside the stream names, with gabions being those constructed in Sachs Creek.

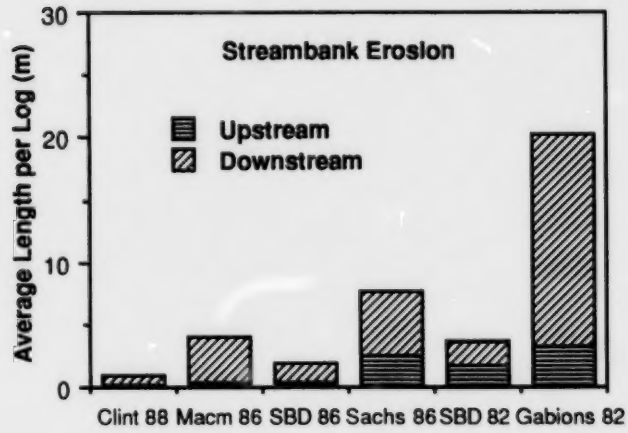

FIGURE 10. Streambank erosion at stream rehabilitation structures in Clint, Macmillan (Macm), Southbay Dump (SBD) and Sachs creeks, February 1989. Year of rehabilitation indicated beside the stream names, with gabions being those constructed in Sachs Creek.

Gabion weirs

Gabion weirs were considered as a possible alternative to logs in creating habitat in streams at the onset of FFIP. Recently, however, their short effective life span has discouraged stream enhancement operations from using them (Crispin 1988; King 1988,. The gabions installed in Sachs Creek as part of FFIP initially generated spawning and rearing habitat (Klassen 1984; Klassen and Northcote 1986, 1988), and in this study they were compared to log placement sites. Of the parameters examined, gabion sites exhibited substantial streambank erosion (Plate 4) and large pool areas.

PLATE 4. Mesh decay and bank erosion at gabion site 2, Sachs Creek, February 1989 .

5.4 Construction Costs

Costs to construct log emplacement sites are for selecting sites, selecting logs, hauling logs to the stream, preparing anchors, placing anchors and logs, and cleaning up the stream. Times required to complete these tasks are given in Table 3. Costs directly associated with site construction totalled $4210 for personnel costs and $2008 for equipment costs. Additional costs were not available for miscellaneous supplies, such as bundling cables and crimps, gloves, and staples. Costs for the three stone lines, 13 log sites (5 with root wads), and one separate root wad averaged $366 for each of the 17 structures.

Per-site costs in Clint Creek were comparable to costs expended in other Queen Charlotte Islands stream rehabilitation studies. Although the per-log costs of installation in Sachs, Macmillan and Southbay Dump creeks averaged slightly less than that in Clint Creek (Figure 11), the per-site average cost of $790 in these streams (V.A. Poulin & Assoc. Ltd. In press) reflected the frequent installation of multiple-log structures. The high cost of multiple-log structures in the 1986 study was not compensated by improved per-log habitat values (section 5.1.3). Rather, the lower overall habitat production per log in the 1986 study compared to that of the Clint Creek study suggests that the multiple-log structures were inefficient.

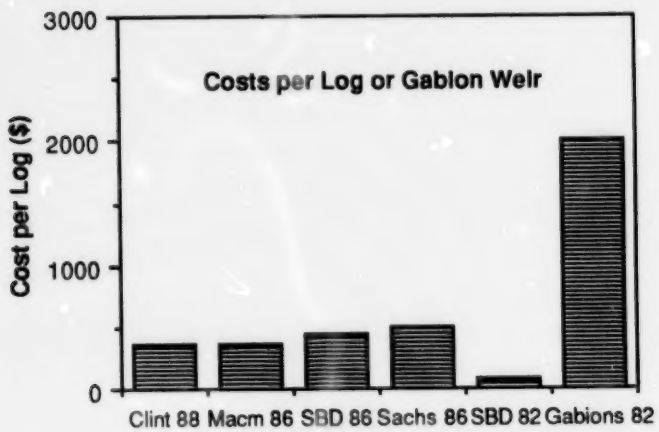

FIGURE 11. Construction costs of stream rehabilitation structures on the Queen Charlotte Islands. Costs for Macmillan, Southbay Dump and Sachs creeks 1986 log emplacements from V.A. Poulin & Associates Ltd. (In press); costs for Southbay Dump 1982 log emplacements from Tripp (1986); and costs for Sachs Creek gabion weirs from Klassen (1984).

TABLE 3. Construction time requirements for rehabilitation of Clint Creek, 1988

Category	Time spent
Selecting and flagging log emplacement sites	5 hr
Selecting logs and root wads	4 hr
Hauling logs and root wads to stream (Cat 980/ truck)	7 hr
Carrying/skidding logs to sites (excavator)	3 hr
Pre-construction access and riparian brush removal (hand work)	20 hr
Anchor preparation (hand work)	
Cutting and crimping cable	3.5 hr
Rolling tires and cables to site	4 hr
Filling tires with rocks	incl with construction times
Site construction (excavator time)[a]	
Stone line construction (3 sites)	1.5 hr (avg 0.5 hrs/site)
Log emplacements (13 sites, 5 with root wads)	25 hr (avg 1.9 hrs/site)
Separate root wad placement (1 site)	0.8 hr
Re-anchoring one log and three root wads after flood	2 hr
Excavator repair; entering/exiting stream	7 hr
Site completion and clean-up (hand work)	
Finish cabling logs	3 hr
Hand laying riprap	8 hr
Removing damaged riparian vegetation	35 hr
Seeding exposed soil	3 hr

[a] Operator, biologist and one assistant for all excavator in-stream work.

6 RESTORATION GUIDELINES

Considerable experience has been developed in stream rehabilitation under FFIP and studies elsewhere in the Pacific Northwest. Although the stream systems in northern British Columbia tend to be different from those in southern climates, some of the challenges facing managers are applicable in both. Stream rehabilitation is no longer in its infancy, but its technology is still growing rapidly as new ideas replace the old. Updates on the latest techniques should therefore be consulted before a new rehabilitation project is undertaken.

The following guidelines are provided to assist stream managers in restoration projects.

6.1 Planning and Design

The first step is to select several streams for rehabilitation. Often a stream is selected for you, such as those having a recent debris torrent. To ensure the stream is a candidate for rehabilitation, check for:

- reaches with stream gradients less than 3%. Streamflow energies during floods in reaches greater than 3% tend to be too great in flashy systems to collect streambed sediments successfully.
- fish access to the system.
- machine access to the system, with roads, logs, root wads and equipment nearby.

Consult a biologist about whether the stream has potential to rear particular species of fish and whether stocks will enter the stream after rehabilitation. The biologist should consider the requirements of all aspects of the target species' life history. A survey of fish presently in the system may be required.

Next, consult a fluvial geomorphologist about whether the channel is stable or rapidly downcutting, or whether upstream processes threaten to bury the rehabilitated reach. The geomorphologist will also identify sensitive streambanks to be avoided and potential areas of channel breaching that could leave your project high and dry if a new channel forms. As well, he or she may comment on the frequency of log emplacements required to achieve the desired effect (between one to three bankfull widths). The geomorphologist's comments would also be helpful in establishing relative vertical positions and angles of the logs.

After the candidate streams are selected and an outline of how many and what type of structures is drawn, approach the local Department of Fisheries and Oceans and Ministry of the Environment agencies for a permit to undertake the proposed work. The agencies prefer to issue permits when a biologist plans to be present during construction, to ensure no undue habitat destruction occurs. Best chances for obtaining a permit are for streams badly damaged and presently supporting little or no fish stocks. Construction will probably be restricted to a summer low-flow window when the least number of fish or eggs are present in the system. The agencies may have special requests for a specific system. Do not begin construction until the permits are in hand.

6.2 Site Construction

Draw up a detailed list of requirements by identifying and measuring all potential log placement sites, and by flagging upstream and downstream ends of the site, locations for additional root wads or auxiliary logs, reaches to be avoided, and areas to be riprapped. The list should identify location, configuration and lengths of logs, and anchoring requirements. A sketch map of the stream reach with log configurations and identifying landmarks should accompany the list.

Assign a log for each of the logs identified on the list. As the cost of market logs is high, alternative sources of logs should be explored. These include drift logs, cull logs from sort yards, old boomsticks (before they are too full of toredo holes), or standing timber from overbank areas. Occasionally, long logs are found in debris levees beside torrented streams. Log length is critical. Logs should span the stream at the appropriate angle with sufficient extra length to bury into both streambanks. This keeps the stream from flowing around the log and isolating it from the channel. Log diameters should range from 0.2 to 0.5 m. Anything larger becomes a problem to install and stabilize. Hemlock is the preferred species as it becomes waterlogged the fastest. Cedar lasts longer but floats too easily.

Select an anchoring system. Logs tend to float, so anchors are required to keep logs in place both horizontally and vertically. A log buried 2 m into a streambank anchors it securely, but not all streambanks are high enough for this approach to be used. Use deadmen where the streambank is too low or when a log does not quite span the stream. Truck tires filled with rock work better than logs for deadmen. If deadmen are used, bundling cable or haul-back cable can be used to attach the logs to the anchors. Position the anchors 2 m into the streambed and directly below the upstream side of the log. As an alternative to deadmen, Geogrid mesh attached to the log and buried at least 1 m into the streambed in front of the log will prevent scour under the log, stabilize the log from movement, and help sink the log during vertical positioning.

Select the most appropriate equipment to be used in the stream. An excavator equipped with an opposing thumb is preferred. The smaller the equipment the better environmental damage will be minimized. Ensure all fluid leaks are sealed and, if the equipment is particularly dirty, have it steam cleaned before use in the stream. Stream rehabilitation puts relatively high stress on equipment, so regularly inspect couplings and fittings for new leaks and seal as they occur.

Cut small trees leaning over the sites that would be damaged by the equipment, and remove these to overbank areas. This prevents further damage as a result of stumps and root masses being wrenched out of the streambank and saves time spent in picking out more branches and leaves later.

Transport the logs to the selected sites carefully to avoid undue damage to streambanks and riparian vegetation. Travel in overbank areas rather than down the stream channel wherever possible. Always keep to the gravel bars rather than the channel.

Start installation upstream and work downstream. This prevents a large buildup of sediments that settle downstream of construction activities.

Dig trenches into the streambed wide enough to fit a log and deep enough to achieve the desired vertical elevation and angle. Remove a section of the berm on the downstream side of the trench to drain water ponded in the trench and enable the log to sit as low as possible. Attach the logs to the anchors while the hoe is sinking the log or cinching the cables tight. If cables are used, tie these to the logs with hitches and staple where the cables overlap.

Use overbank areas or gravel bars to store excavated materials temporarily. When backfilling sites, only use stream material and not material or soil from the bank.

Once the logs are anchored, backfill them to prevent them from floating and to reduce water flow under them. Riprap any areas that require protection from erosion.

Seed damaged streambank areas, and remove broken riparian vegetation. Remove all unstable materials, including branches and leaves introduced to the stream, to overbank areas.

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APPENDIX 1. Calculation of modified Petersen population estimate of juvenile coho salmon in Clint Creek, 1988

Modified Petersen estimate = $N = \frac{(M+1)(C+1)}{R+1}$

Where:	13-15 July	27-28 July
M = total number of marked fish in the population =	81	77
C = number of fish in the recapture sample =	287	70
R = number of marked fish captured in sample =	19	11
N = estimate of total number of fish in the population=	1181	462

For the mark recapture estimates, the 95% confidence limits were calculated by the following:

$$\text{Confidence limit} = N \pm 1.96 \sqrt{\{[M^2 (C+1)(C-R)]+[(R+1)^2 (R+2)]\}}$$

Confidence limits for the 13-15 July 1989 population survey were: $700 < X < 1662$

Confidence limits for the 27-28 July 1989 population survey were: $236 < X < 688$

APPENDIX 2. Comparative survey of rehabilitation structures and their streambed configurations for Clint, Macmillan, Southbay Dump and Sachs creeks, February 1989

Stream	No. logs	Position	Pools				Sed. Storage		Bank erosion	Structure integrity		
			No.	No. per Log (%)	Area (m^2)	Area per Log (m^2/log)	Area (m^2)	Area per log (m^2/log)	per log (m/log)	Stable (%)	Buried (%)	Under-scoured (%)
Clint		Upstream	7	54	86	6.6	100	7.7	0.2			
(1988)		Downstream	12	92	209	16.1	87	6.7	0.8			
	13	Total	19	146	295	22.7	187	14.4	1.0	62	15	46
Macmillan		Upstream	7	37	38	2.0	300	15.8	0.3			
(1986)		Downstream	17	89	111	5.8	271	14.3	3.7			
	19	Total	21	110	149	7.8	571	30.1	4.0	74	5	21
Southbay		Upstream	2	15	6	0.5	215	16.5	0.3			
Dump		Downstream	7	54	51	3.9	104	8.0	1.6			
(1988)	13	Total	9	69	57	4.4	319	24.5	1.9	85	15	23
Sachs		Upstream	7	70	89	8.9	34	3.4	2.5			
(1988)		Downstream	7	70	117	11.7	147	14.7	5.2			
	10	Total	14	140	206	20.6	181	18.1	7.7	70	0	50
Sachs		Upstream	3	50	410	68	53	8.8	3.3			
gabions		Downstream	9	150	167	28	83	13.8	17.0			
(1982)	6	Total	12	200	577	96	136	22.6	20.3	66	0	0
Southbay		Upstream	2	14	24	1.7	300	21.4	1.8			
Dump		Downstream	4	29	40	2.9	187	13.4	1.8			
(1982)	14	Total	6	43	64	4.6	487	34.8	3.6	0	0	100

APPENDIX 3. Dimensions and buoyancy of log emplacements in Clint Creek, 1988

Site	Log length (m)	Mid-log diam (m)	Volume (m^3)	Species	Max buoyancy (kg)	Stability
1	12	0.7	4.6	yellow cedar	1940	Stable
2	11	0.95	7.8	yellow cedar	3270	Floated
3	11.5	0.55	2.7	yellow cedar	1150	Floated
4	12	0.55	2.9	yellow cedar	1200	Floated
5	10.8	0.7	4.2	yellow cedar	1750	Stable
6	12.2	0.8	6.1	S. spruce	2940	Undercut
7	12.6	0.65	4.2	yellow cedar	1760	Floated
8	13.5	0.6	3.8	W. hemlock	1300	Stable
9	11.2	0.65	3.7	yellow cedar	1560	Floated
10	11	0.7	4.2	yellow cedar	1780	Stable
11	8	0.9	5.1	yellow cedar	2140	Stable
12	8	0.5	1.6	yellow cedar	660	Buried
13	8.5	0.65	2.8	yellow cedar	1180	Buried

Where:

Species	Latin name	Specific gravity[ab]	Green weight[b] (kg/m^3)	Maximum buoyancy (kg/m^3)
Yellow cedar	*Chamaecyparis nootkatensis*	0.42	580	420
Redcedar	*Thuja plicata*	0.31	440	560
S. Spruce	*Picea sitchensis*	0.37	520	480
W. Hemlock	*Tsuga heterophylla*	0.42	660	340

[a] Specific gravity = oven dry weight/ weight of displaced volume.

[b] Panshin and de Zeeuw (1980)